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Monitoring Global Surface Soil Moisture with the WindSat Polarimetric Microwave Radiometer

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Introduction: Soil moisture monitoring from space has been designated a very high science and operational priority by the DoD, NOAA, NASA, and the National Research Council Earth Science Decadal Survey. Soil moisture is also a linchpin environmental variable supporting Battlespace Environment assessment/prediction and C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance). Despite the importance of soil moisture applications, current sensors and algorithms do not satisfy measurement requirements. Using data from the NRL WindSat sensor,¹ we have developed a passive microwave land algorithm to retrieve soil moisture and vegetation water content globally from space. The validation results suggest that the algorithm can meet the requirements of 50 km resolution soil moisture mapping under low to moderate vegetation conditions.

Methodology: The WindSat land algorithm is a physically based, multi-channel, maximum-likelihood estimator using 10, 18, and 37 GHz data. The surface parameters considered by the algorithm include soil moisture, vegetation water content, land surface temperature, surface type, precipitation, and snow cover. The solution is found by iteratively minimizing the difference between WindSat measured brightness temperatures and those obtained from radiative transfer simulations. In this way, we can provide retrievals that not only are consistent with our radiative transfer model, but also handle directly the nonlinearity of the vegetation effects and non-uniqueness of the solution.

Results: The retrievals have been validated against multi-scale data including soil moisture climatology, ground in situ network data, precipitation patterns, and vegetation data from AVHRR sensors. Figure 10 shows composite WindSat global surface soil moisture retrievals for the period 20–29 September 2003. Overall, the soil moisture retrievals are very consistent with global dry/wet patterns of climate regimes. All the deserts and arid regions were captured well by the retrievals. In the United States, there are two distinct patterns of continental climate: the humid East and the arid West. The climate transition zone is around the 100° west longitude line, extending through the Great Plains from North Dakota to Texas. Such a pattern of dry in the west and wet in the east is clearly depicted by the

WindSat soil moisture retrievals. They exhibit a distinct and sharp boundary, which agrees well with the strong west-to-east soil moisture gradient near this boundary that is predicted by the NASA Catchment Land Surface Model.²

The quantitative algorithm validation is based on soil moisture data from the top 5 cm soil layer acquired using a dense in situ soil moisture measurement network during the Soil Moisture Experiment (SMEX) over the United States by the U.S. Department of Agriculture.³ The available SMEX data cover the summer months in three years: 2003 in Oklahoma, 2004 in Arizona, and 2005 in Iowa. These three experiment sites provide diverse vegetation covers (rangeland, winter wheat, sparse shrubland, agricultural domain with corn and soybean) and extreme wet and dry soil conditions. Figure 11 plots the area-averaged in situ soil moisture data against the WindSat retrievals for all three SMEX field experiments. In general, the WindSat retrievals agree very well with the in situ data from all the SMEX sites, with an uncertainty of about 4% and bias of 0.4%. The retrieved soil moisture is also highly correlated with in situ data with a correlation coefficient of 0.89.

The comparison of soil moisture retrievals and precipitation patterns offers an indirect, qualitative, but multi-scale way to validate soil moisture retrievals.⁴ As an example, at the synoptic scale, the hot and dry period in July and August 2003 resulted in extreme short-term drought conditions from the western Great Lakes to the northern Rockies and Great Plains, including Nebraska, Kansas, and Oklahoma.⁵ On 11 September 2003, a very heavy rain band developed across the northern and central plains (Minnesota, Nebraska, and Kansas), which lasted for many hours and created ground saturation conditions. Figure 12(a) shows the 24-hour rainfall total for 11 September. The rain band location is illustrated well in the image. By the morning of 12 September, the rain started to move to the east of the Mississippi River and then diminished, as shown in Fig. 12(b). Soil moisture retrievals from the WindSat morning pass on 12 September exhibit a swath lined up well with the rain band on the previous day, and capture the wet event under rain-free conditions. Figure 12(c) and (d) depict the WindSat soil moisture retrievals over the similar region on September 6 and 12, respectively. Figure 12(c) shows mostly very dry conditions prior to the rain event, and Fig. 12(d) the very wet conditions after the rain. Not only are the WindSat soil moisture data able to capture these two extreme dry and wet conditions well, demonstrating sufficient retrieval sensitivity, but the spatial patterns of rainfall and soil moisture also show strong correlations. The locations of the patterns correspond well with each

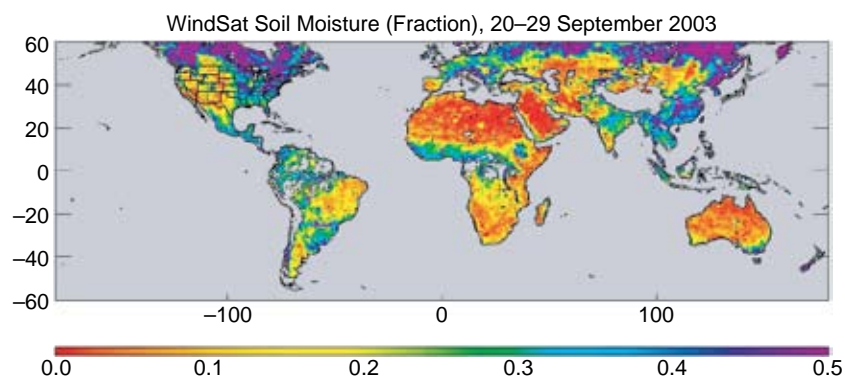


FIGURE 10
Global soil moisture retrievals for 20–29 September 2003.

other, which suggests that WindSat soil moisture data can capture the hydrological processes at the synoptic scale.

Impact: Soil moisture is a desired input to NWP models, including the Navy's NOGAPS and COAMPS® models, because it controls the land-atmosphere interaction, dust emission, and heating/moistening of the lower atmosphere. It also has great importance across the full spectrum of the DoD mission from anti-terrorism operations to major conflicts. Knowledge of the spatial distributions of soil moisture is necessary to support the employment of electro-optical weapon systems; to evaluate mesoscale weather effects; to understand the state of the ground; and, therefore, for trafficability assessment, deployment of ground and amphibious forces, and mine placement and detection. The information is also required for the Future Combat Systems to plan maneuvers on the battlefield in adverse weather conditions.

[Sponsored by NRL and ONR]

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- ⁵ <http://www.ncdc.noaa.gov/oa/climate/research/monitoring.html> ★

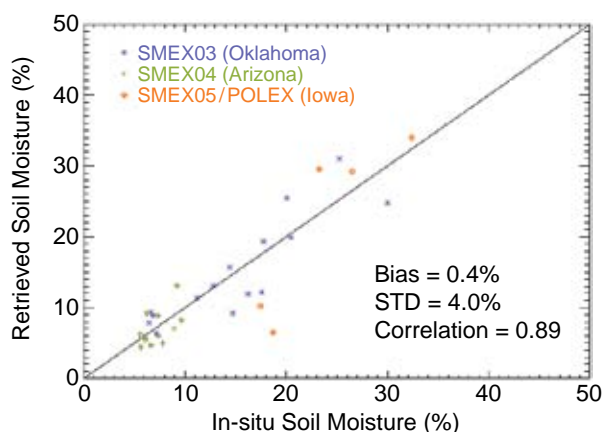


FIGURE 11
WindSat solid moisture validation against SMEX data.

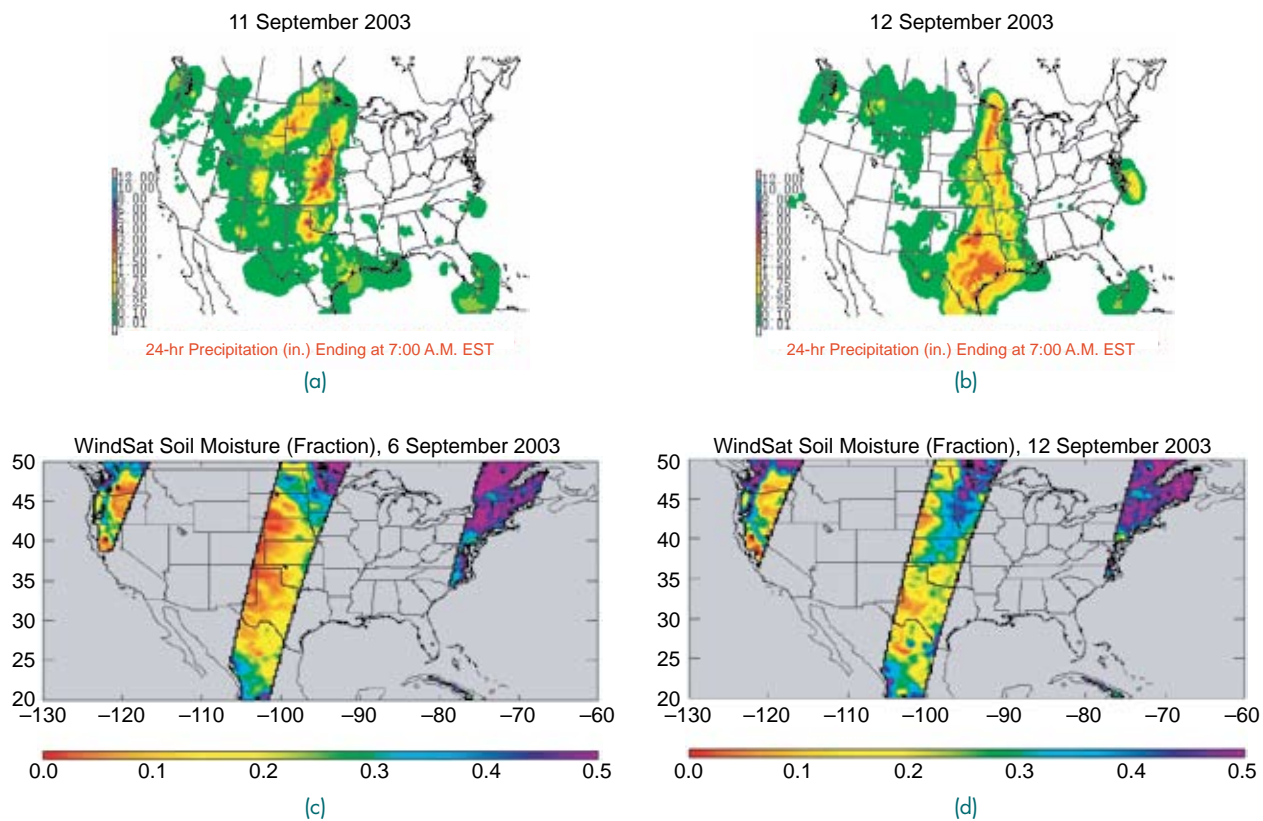


FIGURE 12

Comparisons of precipitation with soil moisture retrievals before and after the rain event. The precipitation images are provided by Dr. Andy Jones, CIRA, Colorado State University.